The Future of Modeling Oceans and Ice

Presented by
Alistair Adcroft
(Stephen Griffies, Robert Hallberg, Matthew Harrison, Sonya Legg, Angelique Melet & Olga Sergienko)

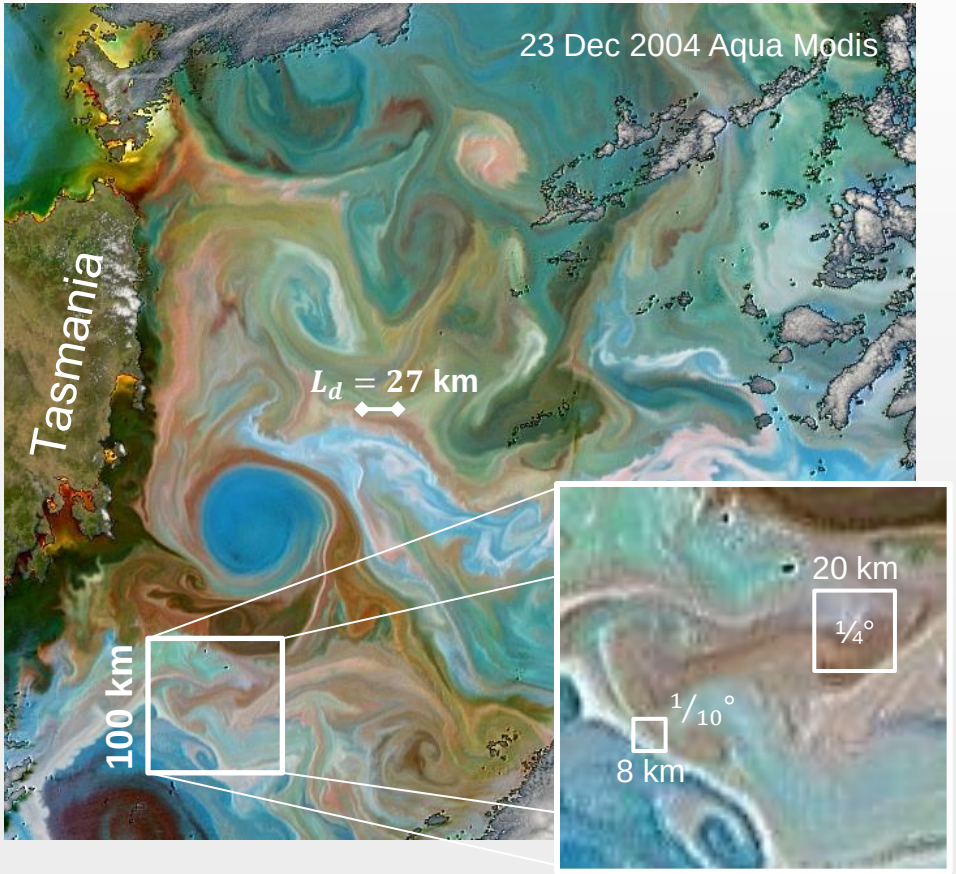
Frontiers in Climate and Earth System Modeling: Advancing the Science

Geophysical Fluid Dynamics Laboratory

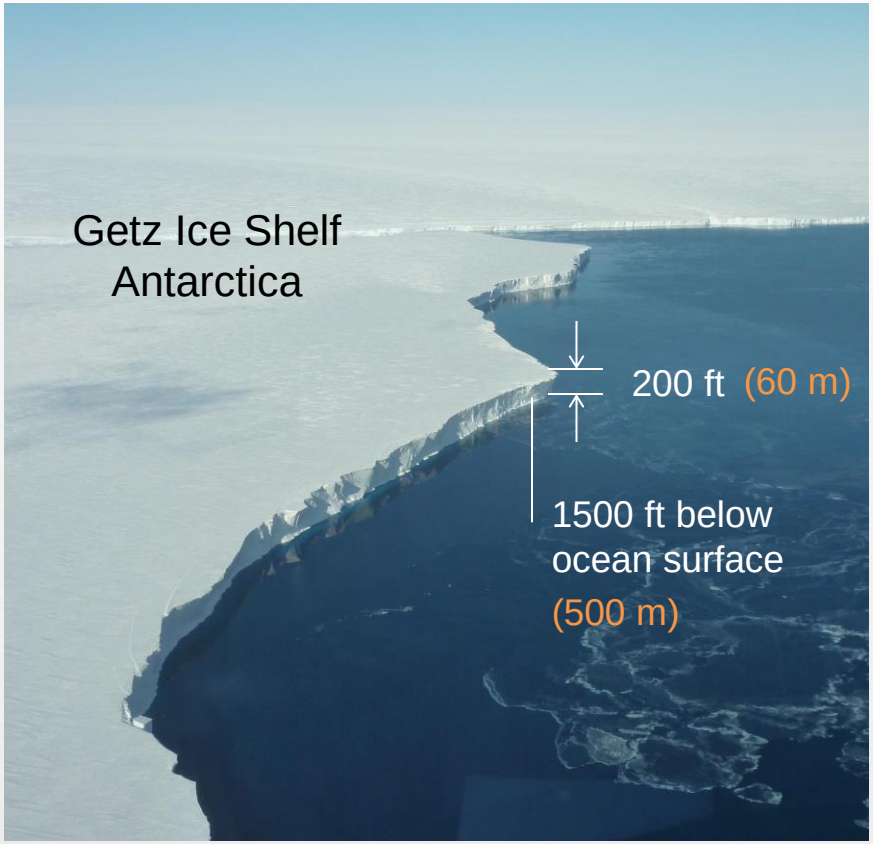
May 20, 2013

Frontiers in ocean/ice-sheet model development

- Role of ocean eddies in climate/earth system



- Sea-level rise and ice-sheet/ocean interaction



Credit: NASA/Dick Ewers

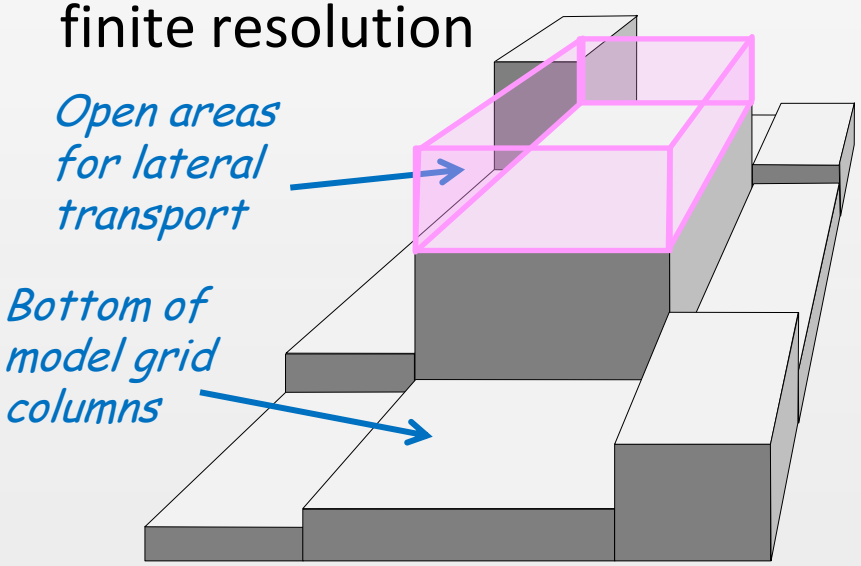
MOM6

- MOM6 unifies the efforts of MOM4/5 and GOLD
  - Initial focus is on construction of p*-coordinate (z-like) ¼° component for CM4
- Arbitrary Lagrangian Eulerian method in the vertical
  - Used for general- & hybrid coordinates
  - Unconditionally stable/accurate
  - **Representation of topography**
  - Wetting/drying
- Global **ice-sheet/ocean coupling**
  - Requires ALE for wetting/drying

- Energetically consistent closures
  - Patchy convection *Ilicak et al, 2013*
  - **Internal wave driven mixing** (CPT)
  - Community software (CVmix)
  - **Eddies in eddy-permitting models**
  - Second order mesoscale closure
- Boundary layer physics
  - Mixed layers
  - Overflows
- Numerics and formulation
  - Transport schemes
  - Solvers
  - Dynamically integrated sea-ice
  - Reduced cost of bio-tracers

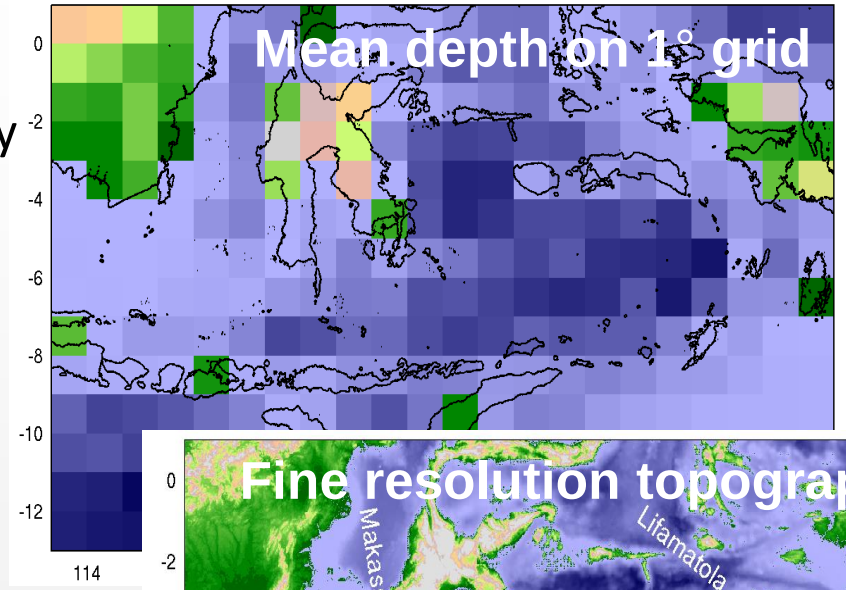
Representation of bathymetry

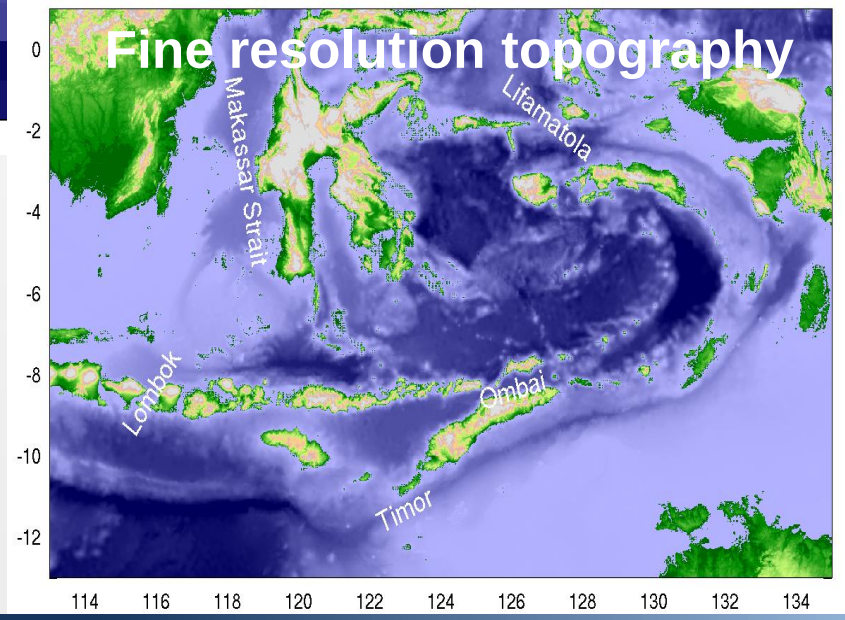
- Ocean bathymetry plays leading role in shaping ocean circulation
  - Modelers always adjust topography because not all features are resolved by a single column value
- Using finite volume methods permits "correct" geometry at finite resolution



Adcroft, 2013

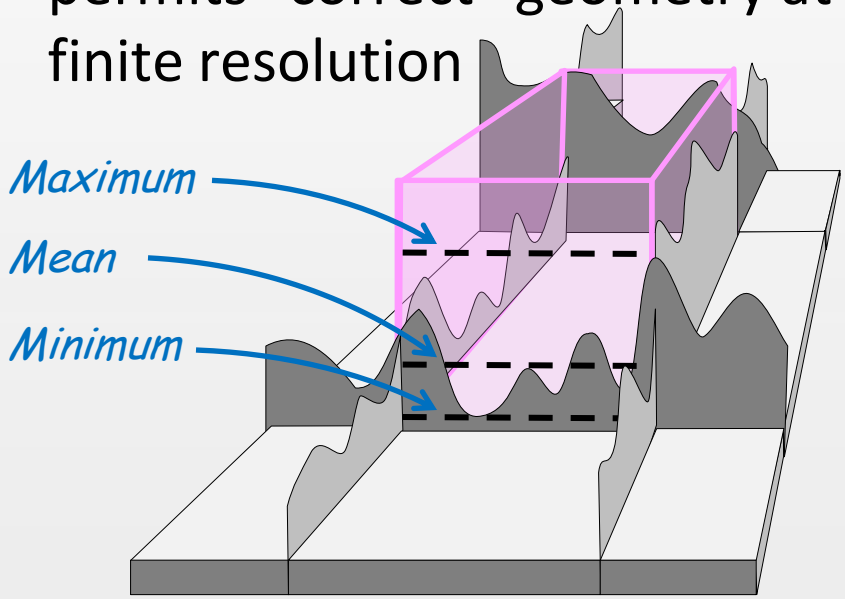
e.g. Indonesian Throughflow





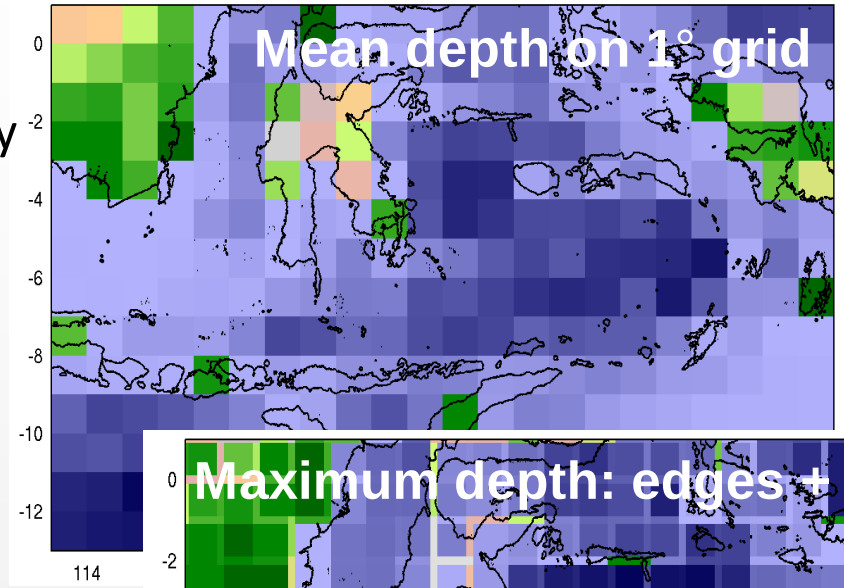
Representation of bathymetry

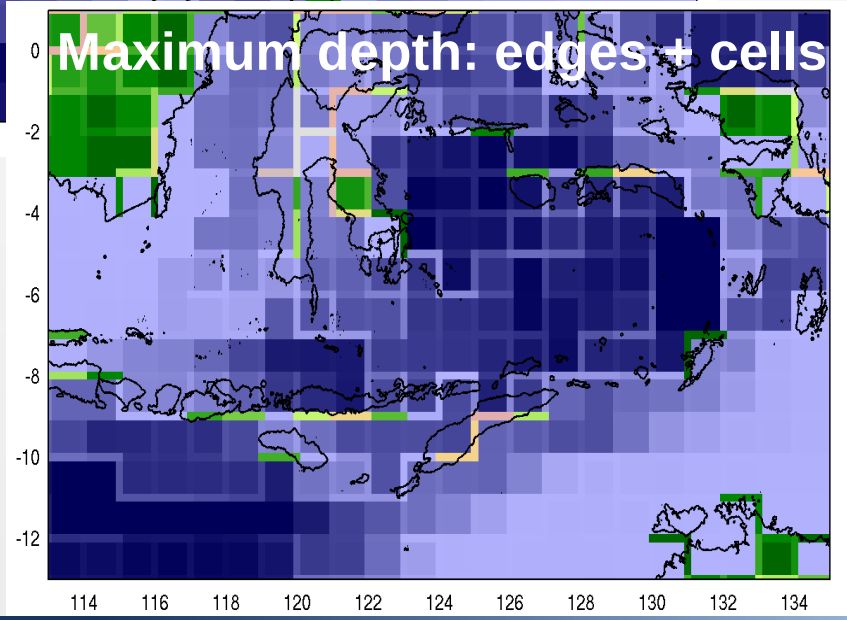
- Ocean bathymetry plays leading role in shaping ocean circulation
  - Modelers always adjust topography because not all features are resolved by a single column value
- Using finite volume methods permits "correct" geometry at finite resolution



Adcroft, 2013

e.g. Indonesian Throughflow

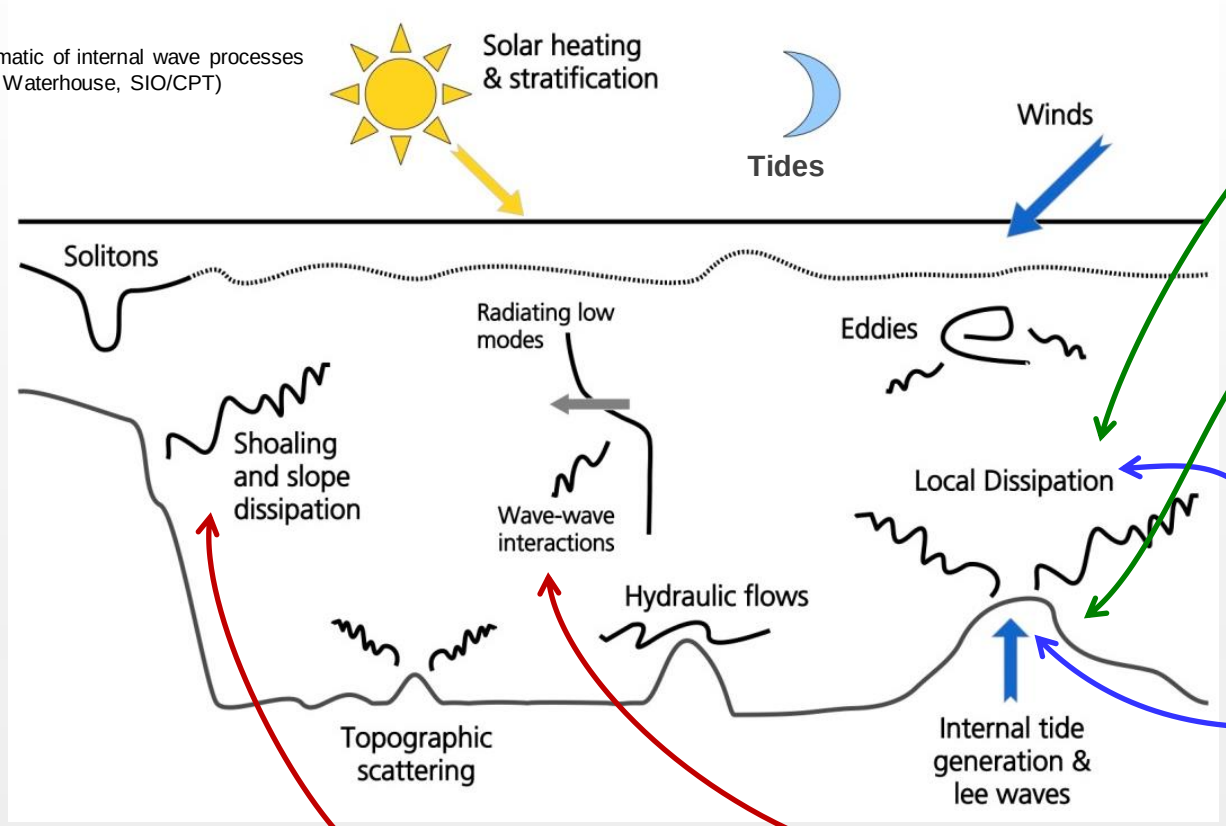




Physically-based, energetically-consistent parameterizations of diapycnal mixing

As part of NOAA/NSF Internal Wave-Driven Mixing **C**limate **P**rocess **T**eam, we are developing and implementing parameterizations of sub-grid-scale mixing which allow mixing to vary spatially and **evolve in a changing climate**.

Schematic of internal wave processes (Amy Waterhouse, SIO/CPT)



Implemented in MOM6:

- Vertical profile of local dissipation. *Polzin, 2009; Melet et al, 2013a*
- Parameterization of lee-waves. *Nikurashin and Ferrari, 2011; Melet et al, 2013b*

Developed:

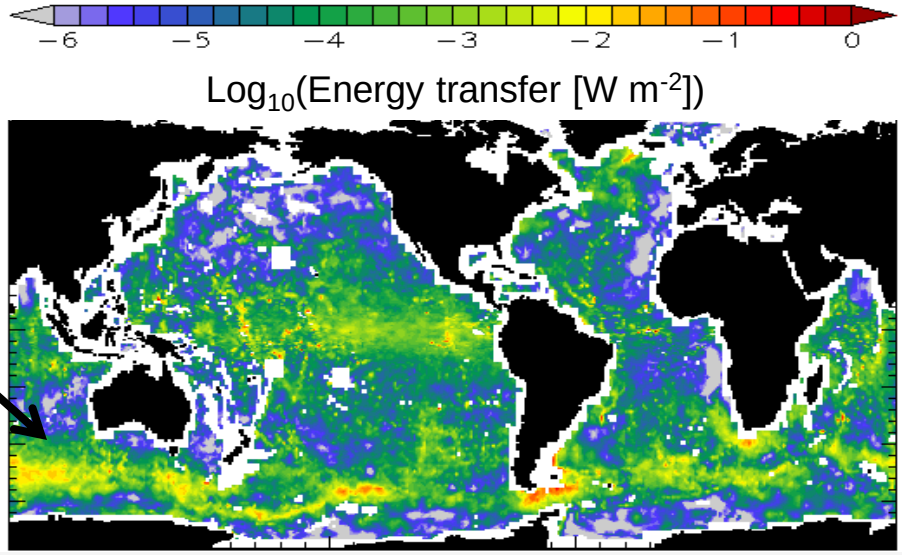
- Local dissipation at tall steep topography. *Klymak, Legg and Pinkel, 2010; Klymak et al, 2012*
- Contribution to generation from abyssal hills. *Melet et al, 2013c*

Under development:

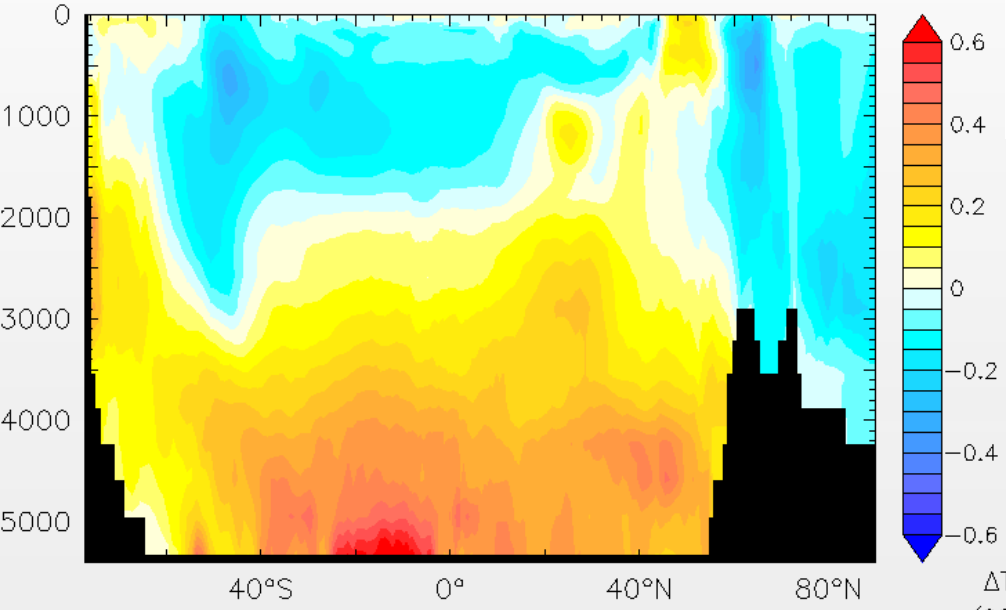
- Low-mode shoaling and reflection. *Legg, 2013*
- Latitudinal dependence of wave-wave interactions. *Nikurashin and Legg, 2011*

CPT: Impact of Lee-wave driven mixing

- Lee-wave energy is most significant in Southern Ocean



Nikurashin and Ferrari, 2011



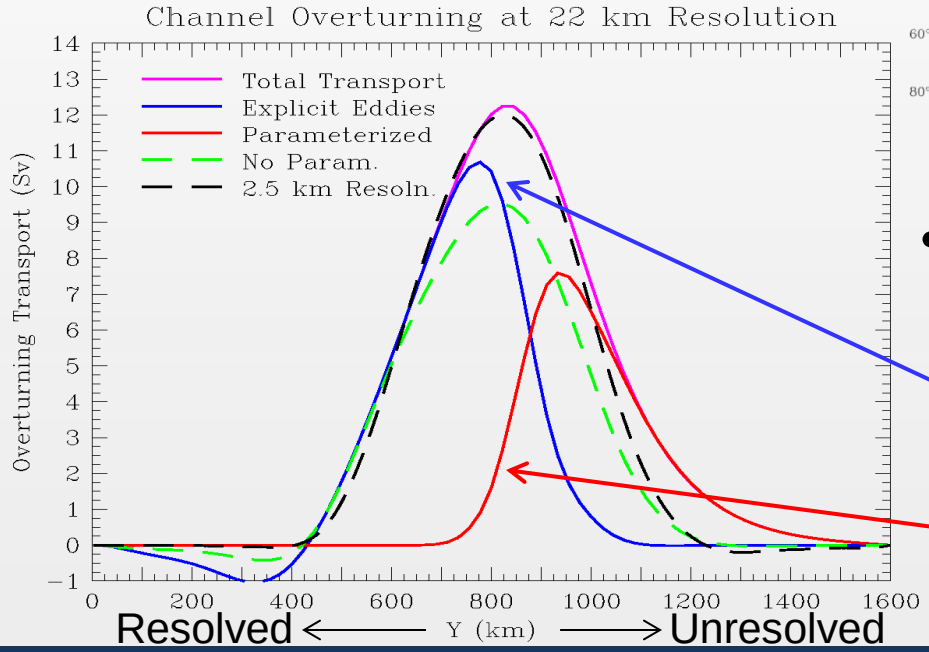
Zonal average temperature change induced in CM2G by extra source of energy for mixing

- Addition of lee-wave driven mixing parameterization systematically warms deep ocean & cools upper ocean
- Adding missing physics improves model credibility

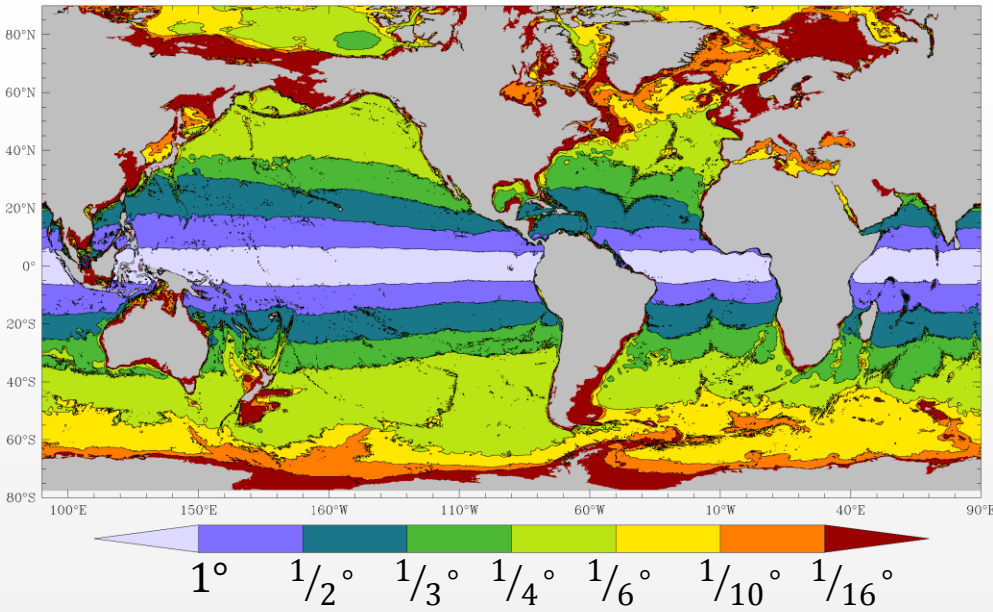
Melet, Hallberg, Nikurashin and Legg, 2013

Parameterizing eddies in an eddy-permitting regime

- Even “fine-resolution” ocean models cannot resolve first-mode eddies everywhere
- Adding a global eddy parameterization dampens the eddies that could be resolved



Mercator resolution that resolves deformation radius



- Resolution-aware eddy parameterization
  - Allows baroclinic instability to proceed when resolution is sufficient
  - Parameterizes eddy fluxes otherwise

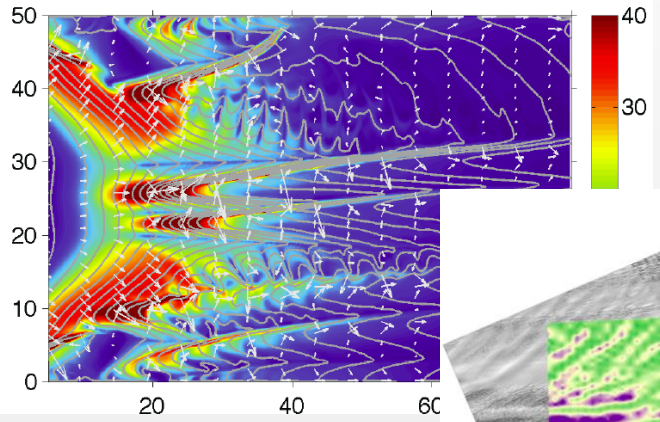
Hallberg, 2013

Ice-sheet/ocean coupling

- Ice-sheet dynamics are biggest uncertainty in sea-level rise
- Dynamics of grounding line is affected by interactions with oceans
- Largest mass loss is observed where warm ocean reaches ice

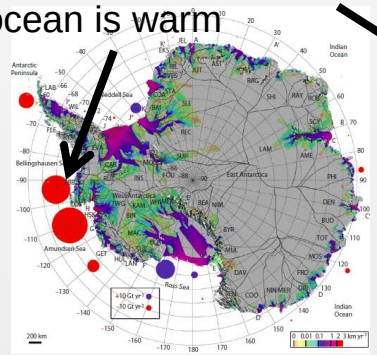
- Confined ice shelves <u>dynamically</u> interacting with warm water spontaneously form melt channels
- MOM6 permits moving grounding lines

Modeled melt rate & ice thickness

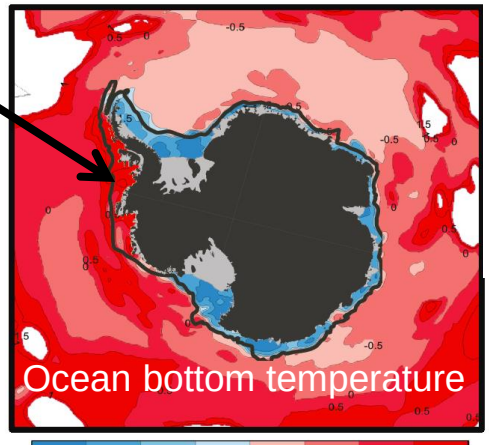


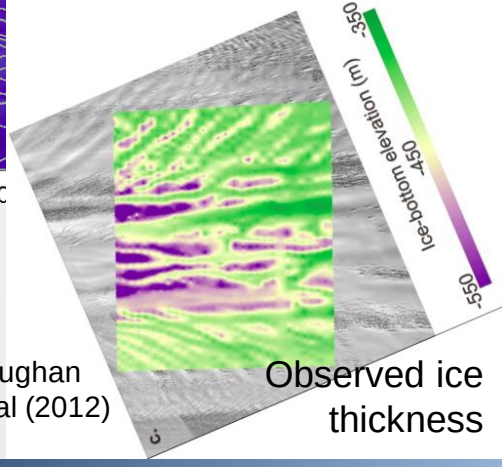
Pine Island Glacier

Mass loss occurs where ocean is warm



Observed mass balance





Vaughan et al (2012)

Observed ice thickness

Goldberg et al. 2012a,b; Sergienko et al, 2013

Directions

- Building towards more flexible ocean model
  - Single unified GFDL ocean model (MOM6)
  - Focus on improving physical content (in contrast to other groups working on alternative horizontal grids)
- Increasingly realistic capabilities
  - Narrow channels, overflows, grounding of icebergs & sea-ice, …
  - Coupled comprehensive ice-sheet model
- Physically consistent formulations
  - Energetically consistent parameterizations
  - More diverse range of phenomena (e.g. tides, eddies, overflows, estuaries)
- MOM6 will follow the long tradition of community ocean modeling